METACOGNITIVE STRATEGIES FOR READING SCIENTIFIC AND SUSTAINABILITY-RELATED CONTENT IN DIGITAL AND PRINT MEDIA

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Abstract

The reading medium - digital or print – Impacts university students' use of metacognitive strategies when engaging with sustainability- and science-themed content. The research aims to identify commonly applied strategies and examine how the medium affects their application and comprehension of environmental topics. Seventy students participated in the study, divided into two groups based on their reading medium. Data collection included the Metacognitive Reading Strategies Questionnaire (MRSQ) and a comprehension test focused on sustainability-themed content that incorporated scientific elements, followed by qualitative group discussions. Results indicate that print media foster deeper understanding through reflective strategies, while digital media support selective and rapid reading, providing broader contextual insights but often resulting in more superficial comprehension. These findings highlight the need to adapt curricula to incorporate both sustainability and scientific content in diverse media formats, fostering critical thinking, metacognitive awareness, and both environmental and science literacy. The study emphasizes the role of such adaptations in equipping students with the skills necessary to interpret scientific information, address environmental challenges, and promote sustainable development.

Keywords: *metacognitive strategies, reading comprehension, reading media, science literacy, sustainable content*

Introduction

Over the last decade, digitalization has transformed how we access information while raising concerns about its impact on understanding and perception. This is especially relevant as sustainability- and science-related texts demand reflection and source evaluation. Sustainability and science often overlap, especially in fields like environmental science and climate change, requiring critical interpretation. This study addresses the relationship between reading media, specifically online and print reading, and the use of metacognitive strategies in understanding such content, emphasizing that the reading process in educational contexts should go beyond acquiring information; it should involve critical thinking, reflection, and evaluation of information credibility – all of which may be shaped by the reading medium.

Although the study focuses on Slovenian university students, its findings have broader relevance for international higher education, especially amid global shifts toward

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digital learning and increased emphasis on sustainability and science literacy. While it does not propose a novel theoretical or methodological framework, it contributes by applying established models – Bloom's revised taxonomy and the Metacognitive Reading Strategies Questionnaire – to a timely and underexplored context. It explores how university students engage metacognitively with sustainability- and science-related content across digital and print media. These findings provide practical insights for fostering critical thinking, metacognitive awareness, and adaptive reading strategies, informing curriculum design aligned with the demands of 21st century learning.

The next section defines key concepts related to metacognitive reading strategies in science and sustainability contexts, followed by the research aim and questions. The methodology outlines the design, instruments, and analytical procedures. Results detail strategy use and comprehension outcomes across reading formats. The discussion interprets the findings and suggests practical implications. The paper concludes with relevance for education and directions for future research.

The Importance of Metacognitive Strategies in Reading

Metacognition is one of the processes that can help us learn about the process of being aware of and in control of one's own thoughts (Drigas & Mitsea, 2021; Flavell, 1976). It encompasses not only awareness but also the regulation of cognitive processes, including deep knowledge, planning, self-monitoring, and adaptation (Drigas & Mitsea, 2021), which improve the quality of learning by allowing the learner to monitor, regulate and organize his or her cognitive processes (Rivas et al., 2022), positioning metacognition as a key component of effective and autonomous learning. It also facilitates the transfer of self-regulation skills to different learning domains. Learners who use metacognitive strategies tend to be more successful in online learning and self-regulation (Anthonysamy et al., 2020). Their reading comprehension and overall reading ability are also improved, which indirectly leads to better academic achievement (Köse & Güneş, 2021; Mihud et al., 2020). Typical metacognitive reading strategies include note-taking while reading, highlighting important information, focusing on key details, reviewing text content, formulating questions, making predictions, and engaging in self-regulatory practices (Drigas & Mitsea, 2021). Such strategies are particularly recommended for reading digital texts, where distraction and nonlinearity are common (Kimova et al., 2024). To enhance learning outcomes, it is essential to integrate metacognitive strategy instruction into educational programs. This enables learners to plan, monitor, and adapt their strategies according to task demands (Wing Han Chan et al., 2021), thereby fostering critical thinking, self-regulated learning, and decision-making, even in complex learning environments (Pandey & Mohan, 2024).

Sustainability Themes and Critical Thinking

Critical thinking is essential for tackling global issues (Fandiño Parra et al., 2021) and is closely linked to understanding sustainability topics, which are one of the key elements of learning in the 21st century classroom (Wing Han Chan et al., 2021). Sustainability education empowers learners as active agents of change (Jónsson et al., 2020) and is relevant at all levels of education (Zwickle & Jones, 2018). Davies (2015)

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emphasizes that sustainability and critical thinking should be treated as distinct yet complementary skills. Sustainability texts often include scientific explanations, data, and causal reasoning – central to science literacy. Metacognitive awareness supports deeper understanding of both environmental and scientific content, fostering informed and reflective engagement with global challenges.

Differences Between Reading Digital and Printed Texts

Metacognitive reading strategies should be more systematically embedded in university education, as students often make limited use of them (Anthonysamy et al., 2020), and reading comprehension is reportedly declining (Ribeiro et al., 2019). Reading is shaped by the medium (Habok et al., 2024; Oshima, 2024), and digital environments pose specific challenges. Strategies such as note taking, identifying key information, reviewing content, posing questions, making predictions, sustaining attention, and engaging in self-regulation play a crucial role in digital environments (Klimova et al., 2024). Digital texts, especially longer and more complex ones, are often perceived as more difficult to follow (Baron, 2021), which may explain readers' preference for print in depth reading (Spencer, 2006). However, digital texts also offer unique affordances, such as hyperlinking and multimedia integration, which provide ways to engage with information and support reading flexibility, which is also noticed by Furenes et al. (2021). These differences matter especially when reading science-based and sustainability texts, which require both surface-level scanning and deeper reflection. Understanding how each medium shapes strategy use is key to developing effective educational practices.

Research Aim and Questions

Although many studies address specifics of online reading, little attention has been given to how different reading media affect the use of metacognitive strategies when engaging with sustainability- and science-related content. Such texts require not only comprehension but also critical evaluation, integration of prior knowledge, and higher-order thinking. Prior research highlights the role of metacognition in learning and addressing sustainability challenges (Bohm, 2024). Deep learning supports meaning-making in complex domains like sustainability education (Warburton, 2003), which often relies on scientific reasoning and data interpretation.

This study, therefore, explored how university students' use of reading media affects their use of metacognitive reading strategies when engaging with sustainability-related content that requires critical thinking and source evaluation skills. The purpose of the study was to identify which strategies are most commonly used and to determine how different reading media affect students' ability to understand and engage with scientific and sustainability-oriented content. By doing so, the study aims to inform educational practices that promote deeper comprehension and critical engagement with complex informational texts across formats.

The research was guided by two research questions: (1) How do university students use metacognitive strategies when reading about sustainability- and science-infused content, and which strategies are most common? (2) How do different types of texts (digital or print) affect their use of metacognitive strategies and their understanding of sustainability and science-related topics?

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Research Methodology

General Background

Understanding how reading medium affects the activation and use of metacognitive strategies is particularly important when students encounter cognitively demanding texts – such as those related to sustainability and science – that require data interpretation, causal reasoning, and critical reflection. Prior research highlights the importance of self-regulation and resource management in digital reading contexts (Zheng & Kim, 2025). Eye-tracking studies further suggest that print and digital formats activate different cognitive processes: printed texts foster focused rereading, while digital texts are often associated with scanning (Jian, 2022). Students themselves tend to associate print with deeper engagement and comprehension – especially in academic contexts (Hargreaves et al., 2022).

Conducted in October 2024, the research employed a quantitative, between-subjects experimental design to compare students' use of metacognitive strategies and comprehension outcomes across reading formats. The theoretical grounding combines Flavell's metacognitive theory (1979), which frames reading as a self-regulated, strategic process, with Bloom's revised taxonomy (Anderson & Krathwohl, 2001), used to assess comprehension depth. The study was carried out at a single Slovenian university, providing controlled conditions while limiting broader generalizability.

Participants

The study involved 70 fourth-year undergraduate students from a teacher education program at a Slovenian faculty of education. All participants were enrolled in a didactics course focused on mother tongue instruction, where reading strategies and media are regularly discussed. The average age of the participants was 22.4 years. The sample included 67 female and 3 male students; however, due to the low number of male participants, no gender-based comparisons were conducted.

Participants were recruited from the same course group, with no exclusion criteria applied. The activity was part of regular coursework, the participation in the study was voluntary, and all the students present agreed to participate. They received written information about the research aims and gave informed consent, and they were assured of their right to withdraw at any time without penalty.

To enable comparative analysis, students were randomly assigned to two equally sized groups: one read a printed version of the text, and the other used personal digital devices to access the same content. The sample size was determined by course availability and the need for balanced groups with sufficient statistical power.

Instrument and Analytical Methods

For the purpose of this study, two measurement instruments were used: the Metacognitive Reading Strategies Questionnaire (MRSQ), based on Taraban (2004), and a custom-designed reading comprehension test.

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Since sustainability topics are often not formally included in university curricula in Slovenia, students tend to encounter such content through non-academic sources (Kerneža & Zemljak, 2024), particularly in the form of reading current articles on news websites. Therefore, the most up-to-date article on the most read Slovenian news portal (as reported by MOSS) was selected as the primary reading material. Students in the digital group read the article on their smart devices, while the other group received a printed copy of the identical text.

Participants rated their reading strategies on the MRSQ questionnaire in the form of a 5-point Likert scale (1 – never, 5 – always), which allowed for a quantitative measurement of the frequency of use of the strategies. The questionnaire demonstrates high validity and internal reliability, and meaningful interpretability (Taraban, 2004).

To assess reading comprehension, a researcher-developed test was constructed based on Bloom's revised taxonomy (Anderson & Krathwohl, 2001). The test included six open-ended questions, each corresponding to one of Bloom's cognitive levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. The questions were designed to measure how well students understood, interpreted, applied, and critically evaluated the content of the text. Responses were scored on a 3-point scale (1 – incorrect answer, 2 – partially correct, 3 – fully correct), with a maximum score of 18 points.

The test was reviewed and validated by three pedagogical experts, who evaluated the alignment between the questions and Bloom's taxonomy, refined the wording of items, and established strong criteria. A pilot test was conducted on a small sample of comparable students (n = 7). While the items targeted different skills and therefore did not form a homogeneous scale, internal consistency was assessed using Cronbach's alpha as a general indicator of scoring coherence. The result was 0.871, suggesting high consistency in how the items were interpreted and rated. However, this value should be interpreted with caution given the heterogeneity of the items.

Data Analysis

The data from the MRSQ and the reading comprehension test were analyzed using SPSS (version 27). The separate one-way analyses of variance (ANOVA) were conducted. The first ANOVA compared the frequency of metacognitive strategy use between the two reading media (digital vs. print). The second ANOVA explored differences in reading comprehension outcomes across six cognitive levels based on Bloom's revised taxonomy. Mean scores and standard deviations were calculated for each questionnaire item and comprehension test level. Group means were then compared to determine whether there were statistically significant differences between the two reading formats. Statistical significance was set at $p < .05$.

Research Results

After students read the text, the first step of the survey, the MRSQ questionnaire, was used to compare the use of reading strategies between reading online and reading printed texts. The aim was to determine whether the reading medium affected the frequency and type of metacognitive strategies used during engagement with sustainability- and

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science-related content. The results shown in Table 1 illustrate how the reading format affected the use of various metacognitive strategies.

Table 1

Comparison of Reading Strategy Use Across Online and Printed Texts

Reading medium	Online		Printed	
Reading strategy	***M***	***SD***	***M***	***SD***
While reading, I evaluate the text to see if it contributes to my knowledge/understanding of the topic.	3.4	.69	3.3	.82
After reading a text, I predict how I will apply the knowledge I gained from reading.	3.4	.76	3.1	.81
I try to connect prior knowledge about the topic to better understand what I am reading.	4.1	.71	3.9	.71
While reading, I rethink and adjust my prior knowledge about the topic based on the text's content.	3.3	1.00	3.2	.71
While reading, I rethink and adjust my initial questions about the topic based on the text's content.	3.1	.81	2.9	.85
After reading a text, I reflect on the content of the text	3.6	.77	3.2	.96
While reading, I distinguish between information I already know and new information.	3.9	.78	3.6	.60
When information critical to understanding the text is not directly stated, I try to infer it.	3.5	.77	3.1	.74
I look for information that is important to my reading goals.	3.9	.74	3.8	.76
I predict information that will be presented later in the text.	3.1	.97	3.2	.71
While reading, I try to determine the meaning of unfamiliar words essential for understanding the text.	3.8	.63	3.4	1.07
I predict information that will be presented later in the text.	3.3	.82	3.2	.90
While reading, I use my personal strengths to better understand the text.	3.6	.77	3.2	.76
While reading, I visualize descriptions to better comprehend the text.	3.9	.88	3.5	1.02
I notice how difficult or easy the text is to read.	3.7	1.15	3.6	.68
When reading, I take notes to remember the information.	2.5	.90	2.4	1.02
While reading, I underline and highlight important information to easily locate it later.	3.4	1.17	3.0	1.29
While reading, I write questions and comments in the margins to better understand the text.	2.1	1.13	2.3	1.16
While reading, I underline to remember the information.	3.4	1.02	2.9	1.31
I read the material multiple times to retain the information.	4.0	.67	3.8	.69
When I have trouble understanding the text, I read it again.	4.3	.73	4.1	.62

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The analysis of variance (ANOVA) revealed a statistically significant effect of reading format (F = 10.19, p = .001) and of the type of reading strategy (F = 9.92, p = .001). Although the differences between the media were relatively small, their consistency indicates that the text format affected how students engaged with complex informational content.

Overall, the use of metacognitive strategies was overall slightly more frequent in the digital reading group, suggesting that students who read digitally were more likely to use certain strategies. This tendency was particularly evident in strategies aimed at comprehension and navigation of complex or unfamiliar content. In contrast, students who read printed texts more frequently used strategies oriented towards long-term retention and structured organization of knowledge, such as underlining, rereading, and highlighting.

These findings suggest that print media encouraged more deliberate and reflective reading, supporting the structuring of deeper understanding. On the other hand, digital texts prompted a more flexible and adaptive approach, aligned with fast information retrieval and focused decoding. Such differences in strategy use are particularly relevant in the context of reading science-based and sustainability-oriented texts, which require both surface-level navigation and deeper conceptual understanding.

An additional analysis of variance (ANOVA) was conducted to compare reading comprehension scores across six cognitive levels based on Bloom's revised taxonomy, allowing mean scores to be compared between the two reading groups.

Table 2

Comparison of Reading Comprehension Test Results Across Online and Printed Texts

Reading comprehension level	*M* (Online)	*M* (Print)	*Mean difference*	*p*
Knowledge: Recall of basic facts, concepts, or information	3.00	3.00	.00	1.000
Comprehension: Explanation and interpretation of the meaning of information	2.85	2.94	.09	.090
Application: Applying acquired knowledge to new situations	2.50	2.88	.38	.040
Analysis: Breaking down information into components, identifying patterns, and relationships	2.88	2.97	.09	.200
Synthesis: Combining elements to form a new whole or original solution	2.88	2.94	.06	.330
Evaluation: Judging the value of information or solutions based on specific criteria	2.44	2.85	.41	.030

As shown in Table 2, the two groups performed equally at the knowledge level (M = 3.00, p = 1.000). Differences in comprehension, synthesis, and analysis were small and not statistically significant. However, more pronounced and statistically significant differences emerged at the higher cognitive levels of application (p = .040) and evaluation (p = .030), with students in the print group outperforming those in the digital group.

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For the application level, the effect size was medium (Cohen's $d = 0.47$; $\eta^2 = .188$), showing a clear advantage for print readers in applying knowledge. Similarly, at the evaluation level, the effect size was also medium (Cohen's $d = 0.51$; $\eta^2 = .213$), suggesting that print readers demonstrated greater capacity to critically assess the value and implications of the text content.

A deeper analysis of student responses revealed that printed texts encouraged more elaborate thinking, particularly in questions that involved judgment, conceptual transfer, or synthesis. It should also be noted that students who read printed texts generally took more time to read, which may have contributed to the increased depth of their understanding.

Taken together, these findings suggest that print media provided more effective support for cognitively demanding tasks – particularly application and evaluation – while online reading was more suitable for quicker information retrieval, scanning, and synthesis. The distinction is especially relevant when students are working with texts that include scientific data, sustainability scenarios, or complex cause-effect relationships, where deeper engagement and critical interpretation are essential.

Discussion

The study shows that university students use a wide range of metacognitive strategies when reading complex informational texts related to sustainability and science, which helps them to monitor and adapt their thought processes. This supports earlier findings by Drigas and Mitsea (2021) and Flavell (1976), who highlight the importance of metacognition in planning, monitoring, and regulating cognitive activities in response to textual demands. The finding emphasizes that strategy use depends on the reading goals and text requirements, and in the research conducted, they relied on strategies that helped them to understand and master sustainability content.

Strategies related to understanding difficulties with the text, such as rereading in case of comprehension problems and integrating prior knowledge to improve comprehension, were used most frequently, while strategies of an organizational nature, such as writing down questions and comments in the margin, were used least frequently. While the findings are not in line with those of Anthonysamy et al. (2021), who reported a limited use of metacognitive strategies in reading, participants in the present study demonstrated their application, indicating that there is still room for more systematic instruction and reinforcement of metacognitive strategies, especially as we are talking about adult readers who are also confronted with complex topics such as scientific arguments and sustainability issues.

The type of reading medium affects the use of strategies when reading about sustainability topics, with differences in the choice of strategies depending on the reading medium. In the research conducted, print texts promoted in-depth comprehension to a greater extent, while digital texts enabled selective and rapid reading by searching for key information and skimming through the text. These tendencies reflect the nature of scientific and sustainability content, which often includes abstract concepts, cause-effect reasoning, and data interpretation – all of which benefit from different cognitive approaches. This is consistent with research by Habok and Magyar (2024) and Klimova et al. (2024), who confirmed that digital texts support fast, selective processing, which is essential for effective e-reading strategies.

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Although digital texts offer a broader contextual insight due to the possibility of linking to additional sources, comprehension was often more superficial. During the informal discussion after completing the questionnaire, students who read print texts appeared to demonstrate a deeper understanding of the content, which is supported by the questionnaire results indicating that they used deliberate metacognitive strategies with print texts. This also supports the findings of Baron (2021), who argues that readers often prefer print texts for cognitively demanding content. Such content frequently includes scientific explanations, conceptual models, or data-driven arguments that require more reflective engagement.

Nevertheless, digital texts enable specific metacognitive strategies that are crucial for selective information retrieval and fast access to resources, which is particularly important in modern information environments where users are confronted with large amounts of information, but at the same time, as Lu and Xie (2023) argue, digital tools enable fast and skillful navigation between information, which supports key information retrieval strategies. These affordances of digital media provide opportunities to develop critical thinking, adaptability, and strategic flexibility – skills that are highly valuable for engaging with sustainability content in a digital age.

Rather than treating science literacy as a separate element, the study shows that scientific reasoning is deeply embedded in how sustainability is communicated and understood. Metacognitive strategies therefore play a dual role: they help students comprehend complex environmental issues and also support the interpretation of scientific data, models, or explanations included in such texts. This dual impact was especially evident among students in the print group, where higher performance was observed in tasks requiring application and evaluation – skills that are central to both scientific reasoning and sustainability-oriented decision making.

Although the research was conducted within a specific national and institutional context, the patterns identified in students' strategy use and comprehension across reading media reflect broader educational dynamics. These insights are valuable for other higher education systems aiming to enhance students' science and sustainability literacy in the digital age.

The findings thus emphasize the need for educational practices that promote metacognitive awareness across different reading contexts. Strengthening metacognitive reading strategies can enhance science literacy and prepare students for the cognitive demands of interpreting scientific issues in a real-world context. Digital and printed texts offer complementary advantages, with digital texts providing faster access to information and printed texts providing deeper understanding. This research directly supports curricular innovation through the integration of both sustainability and digital content.

The findings of the research highlight the need to promote the appropriate use of metacognitive strategies when reading about sustainability topics in digital and print media, with implications for both science and sustainability education. This links with the research of Xie et al. (2023), who confirmed that metacognitive strategies when reading science texts have an impact on science literacy. Such strategic reading contributes to both sustainability awareness and the digital empowerment of learners, strengthening their competencies for informed decision-making and promoting sustainable lifestyles.

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Among the major limitations of the study is the singular insight into the situation within a specific population, which limits generalization to the general population. The study also did not involve long-term observations or in-depth qualitative practices. Future research should include a more diverse sample of learners, including primary and secondary school students, and explore how specific technologies – such as interactive platforms, annotation tools, or artificial intelligence – can support or potentially hinder the development of metacognitive strategies when engaging with science-rich sustainability content.

Conclusions and Implications

The research highlights the key role of metacognitive strategies in university students' reading of sustainability- and science-related content across different reading media. The results show that the students adapt their strategic behavior based on the format of the text, with each medium supporting different cognitive processes. Digital reading allows for quick information retrieval and supports selective, goal-directed strategies, while print reading fosters deeper comprehension, structured reflection, and critical thinking. These findings underscore the importance of teaching students how to navigate and regulate their understanding when faced with complex informational texts that require both environmental and scientific literacy. The ability to apply and evaluate content – skills associated with higher-order thinking – was more pronounced among students who read printed texts, suggesting that reflective metacognitive strategies are especially important for mastering cognitively demanding material.

By promoting metacognitive awareness and flexibility in strategy use, educators can help students develop the competencies needed to interpret scientific data, engage with sustainability discourse, and make informed, responsible decisions in a global context. The integration of both digital and print formats in educational settings should be intentional and purpose-driven, aligned with the reading task and desired learning outcomes.

Ultimately, strengthening metacognitive reading strategies prepares students not only for academic success but also for the critical interpretation of scientific and sustainability challenges that define contemporary society. In doing so, they become not only better learners but also more empowered and responsible global citizens.

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